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A basin-scale comparison of constrained BEM and actuator disc models

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Summary: In this abstract, we compare the basin-scale performance of tidal turbines represented using the volume flux-constrained actuator disc (AD) and blade element momentum (BEM) theories. For the more realistic BEM model, the available power is found to be at least 25% lower than that predicted by the AD model and the importance of 'tuning' turbines, i.e. optimising their resistance by adjusting the pitch or rotational speed of the turbine blades, is greatly reduced.

Introduction

Actuator disc theory provides what is perhaps the simplest representation of an axial flow turbine. Actuator disc models are widely used in the basin-scale modelling of tidal turbines, where they provide an inexpensive means of capturing blockage effects. Such models have been used to provide upper bound estimates of tidal stream energy resources and to demonstrate the need to 'tune' turbines to maximise their power output [1]. Here we compare the basin-scale performance of tidal turbines represented using the volume flux-constrained actuator disc (AD) and blade element momentum (BEM) theories. Though still idealised, the BEM model provides a more accurate description of turbine performance than does the AD model.

Methods

To model the turbines, we use the volume flux-constrained AD model of Garrett & Cummins [2] and the volume flux-constrained BEM model of Vogel [3], which extend the respective classical theories to incorporate blockage effects. For the BEM model, we use a fixed rotor design (a fixed number of blades and a fixed solidity) with the specifications of the Risø-A1-24: a 24% thickness aerofoil section that has been used to validate the model against the blade-resolved simulations of Wimshurst & Willden [4]. Basin dynamics are simulated using the simple channel model of Garrett & Cummins [5], for which we specify non-linear bed friction and employ a Runge-Kutta solver. Turbines are arranged in full-width, high blockage (B=0.4) rows and their performance characteristics are represented by the local resistance coefficient k (see figure 1).

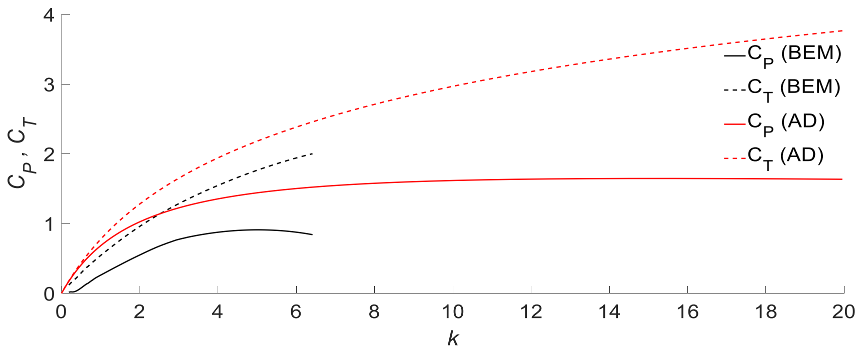

Figure 1: Variation of power and thrust coefficient for the highly blocked (B=0.4) BEM and AD models.

Results

We first consider the case in which the local resistance k is temporally fixed, i.e. does not vary over the tidal cycle. Figure 2*a* compares the maximum time-averaged power available to the BEM and AD models, and shows the power available to the BEM model to be at least 25% lower than that predicted by the AD model. Figure 2*b* shows how the optimal temporally fixed k varies with the channel's natural dynamic balance λ_0 [e.g. 5]. The importance of turbine tuning is greatly reduced for the BEM model because the more realistic turbines are unable to exert sufficient thrust on the flow for their resistance to become significant. It is worth noting, however, that these results may vary with the design of the rotor chosen for the BEM model.

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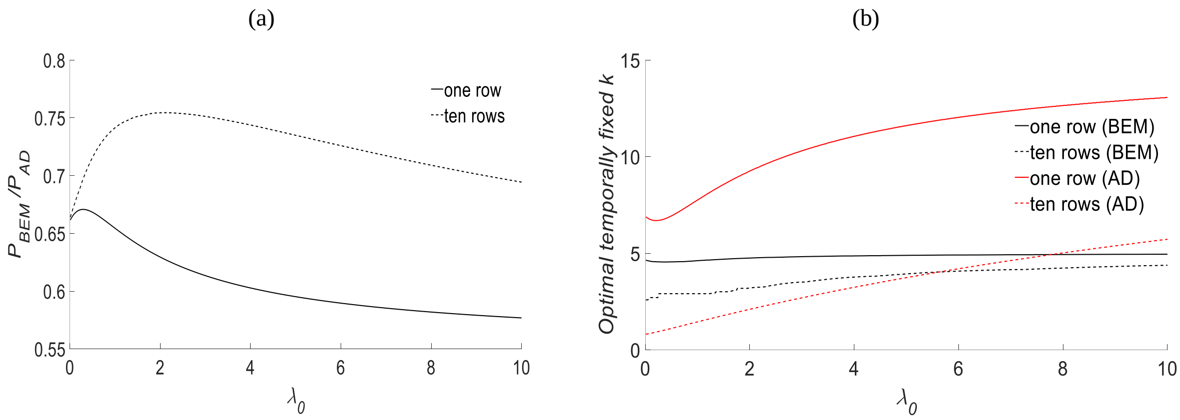

Figure 2: Comparison between BEM and AD models with temporally fixed local resistance *k*: variation of (a) maximum time-averaged available power, and; (b) optimal temporally fixed *k*.

Following Vennell & Adcock [6], we also consider the case in which the local resistance *k* of 5 uniform rows is varied over the tidal cycle. Calculating the optimal temporally variable *k* is a difficult optimisation problem and whilst we are confident that we have identified the key trends, we acknowledge that we may be slightly short of the global optimum. Figure 3*a* compares the (near) optimal temporal variation in *k* for the BEM and AD models, whereas figure 3*b* shows the potential increase in available power for both models relative to the case of temporally fixed *k*. The use of a temporally varying *k* is found to increase the power available to turbines in inertia-dominated channels but the benefits of time-varying tuning are shown to be relatively minor, particularly for the more realistic turbines.

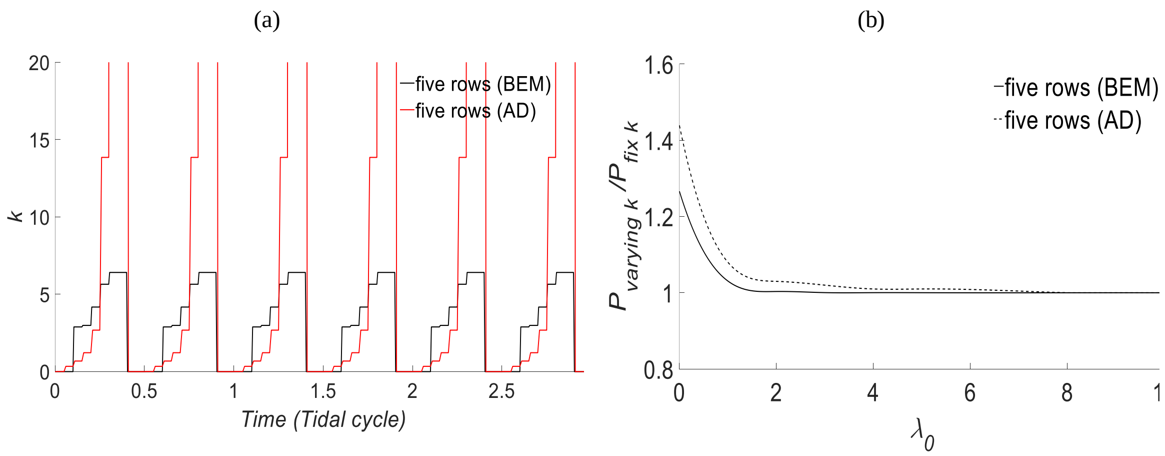

Figure 3: Comparison between BEM and AD models with temporally variable local resistance *k*: variation of (a) (near) optimal temporally variable *k*, and; (b) maximum time-averaged available power relative to temporally fixed *k*.

Conclusions

We have found that, as expected, actuator disc theory significantly overpredicts the amount of power available to more realistic models of tidal turbines. We have also shown turbine tuning to be relatively unimportant for more realistic turbines because they are unable to exert sufficient thrust on the flow for their resistance to become significant.

References:

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